An attractive system for spacing nanoparticles involves the addition of one free linking oligonucleotide as illustrated in Figure 2. The sequence of the linking oligonucleotide will have at least a first portion and a second portion for binding to oligonucleotides on nanoparticles. This system is basically the same as utilized in the nucleic acid detection method, except that the length of the added linking oligonucleotide can be selected to be equal to the combined lengths of oligonucleotides attached to the nanoparticles. The related system illustrated in Figure 3 provides a convenient means to tailor the distance between nanoparticles without having to change the sets of nanoparticle-oligonucleotide conjugates employed.

A further elaboration of the scheme for creating defined spaces between nanoparticles is illustrated in Figure 4. In this case a double stranded segment of DNA or RNA containing overhanging ends is employed as the linking oligonucleotide. Hybridization of the single-stranded, overhanging segments of the linking oligonucleotide with the oligonucleotides attached to the nanoparticles affords multiple double-stranded oligonucleotide cross-links between the nanoparticles.

Stiffer nanomaterials and nanostructures, or portions thereof, can be generated by employing triple-stranded oligonucleotide connectors between nanoparticles. In forming the triple strand, one may exploit either the pyrimidine:purine:pyrimidine motif (Moser, H.E. and Dervan, P.B. *Science,* **238**, 645-650 (1987) or the purine:purine:pyrimidine motif (Pilch, D.S. et al. *Biochemistry*, **30**, 6081-6087 (1991). An example of the organization of nanoparticles by generating triple-stranded connectors by the pyrimidine:purine:pyrimidine motif are illustrated in Figure 10. In the system shown in Figure 10, one set of nanoparticles is conjugated with a defined strand containing pyrimidine nucleotides and the other set is conjugated with a complementary oligonucleotide containing purine nucleotides. Attachment of the oligonucleotides is designed such that the nanoparticles are separated by the double-stranded oligonucleotide formed on hybridization. Then, a free pyrimidine oligonucleotide with an orientation opposite that for the pyrimidine strand linked to the nanoparticle is added to the system prior to, simultaneously with, or just subsequent to

mixing the nanoparticles. Since the third strand in this system is held by Hoogsteen base pairing, the triple strand is relatively unstable thermally. Covalent bridges spanning the breadth of the duplex are known to stabilize triple-stranded complexes (Salunke, M., Wu, T., Letsinger, R.L., *J. Am, Chem. Soc.* **114**, 8768-8772, (1992). Letsinger, R.L. and Wu, T. *J. Am Chem. Soc.*, **117**, 7323-7328 (1995). Prakash, G. and Kool, *J. Am. Chem. Soc.*, **114**, 3523-3527 (1992).

For construction of nanomaterials and nanostructures, it may be desirable in some cases to "lock" the assembly in place by covalent cross-links after formation of the nanomaterial or nanostructure by hybridization of the oligonucleotide components. This can be accomplished by incorporating functional groups that undergo a triggered irreversible reaction into the oligonucleotides. An example of a functional group for this purpose is a stilbenedicarboxamide group. It has been demonstrated that two stilbenedicarboxamide groups aligned within hybridized oligonucleotides readily undergo cross-linking on irradiation with ultraviolet light (340 nm) (Lewis, F.D. et al. (1995) *J Am. Chem. Soc.* **117**, 8785-8792).

Alternatively, one could employ the displacement of a 5'-O-tosyl group from an oligonucleotide, held at the 3'-position to a nanoparticle by a mercaptoalkly group, with a thiophosphoryl group at the 3'-end of an oligonucleotide held to an nanoparticle by a mercaptoalkyl group. In the presence of an oligonucleotide that hybridizes to both oligonucleotides and, thereby, brings the thiophosphoryl group into proximity of the tosyl group, the tosyl group will be displaced by the thiophosphoryl group, generating an oligonucleotide linked at the ends to two different nanoparticles. For displacement reactions of this type, see Herrlein et al., *J. Am. Chem. Soc.*, **177**, 10151-10152 (1995). The fact that thiophosphoryl oligonucleotides do not react with gold nanoparticles under the conditions employed in attaching mercaptoalkyl-oligonucleotides to gold nanoparticles enables one to prepare gold nanoparticle-oligonucleotide conjugates anchored through the mercapto group to the nanoparticles and containing a terminal thiophosphoryl group free for the coupling reaction.

A related coupling reaction to lock the assembled nanoparticle system in place utilizes displacement of bromide from a terminal bromoacetylaminonucleoside by a terminal thiophosphoryl-oligonucleotide as described in Gryaznov and Letsinger, *J. Am. Chem. Soc.*, **115**, 3808. This reaction proceeds much like the displacement of tosylate described above, except that the reaction is faster. Nanoparticles bearing oligonucleotides terminated with thiophosphoryl groups are prepared as described above. For preparation of nanoparticles bearing oligonucleotides terminated with bromoacetylamino groups, one first prepares an oligonucleotide terminated at one end by an aminonucleoside (*e.g.*, either 5'-amino-5'-deoxythymidine or 3'-amino-3'-deoxythymidine) and at the other end by a mercaptoalkyl group. Molecules of this oligonucleotide are then anchored to the nanoparticles through the mercapto groups, and the nanoparticle-oligonucleotide conjugate is then converted the N-bromoacetylamino derivative by reaction with a bromoacetyl acylating agent.

A fourth coupling scheme to lock the assemblies in place utilizes oxidation of nanoparticles bearing oligonucleotides terminated by thiophosphoryl groups. Mild oxidizing agents, such as potassium triiodide, potassium ferricyanide (see Gryaznov and Letsinger, *Nucleic Acids Research*, **21**, 1403) or oxygen, are preferred.

In addition, the properties of the nanomaterials and nanostructures can be altered by incorporating into the interconnecting oligonucleotide chains organic and inorganic functions that are held in place by covalent attachment to the oligonucleotide chains. A wide variety of backbone, base and sugar modifications are well known (see for example Uhlmann, E., and Peyman, A. *Chemical Reviews*, **90**, 544-584 (1990). Also, the oligonucleotide chains could be replaced by "Peptide Nucleic Acid" chains (PNA), in which the nucleotide bases are held by a polypeptide backbone (see Wittung, P. et al., *Nature*, **368**, 561-563 (1994).

As can be seen from the foregoing, the nanofabrication method of the invention is extremely versatile. By varying the length, sequence and strandedness of the linking oligonucleotides, the number, length, and sequence of the binding portions of the linking oligonucleotides, the length, sequence and number of the oligonucleotides attached to the nanoparticles, the size, shape and chemical composition of the nanoparticles, the number and